AS Unit 1: Basic Biochemistry and Cell Organisation

Name:	Date:

<u>Topic 1.3 Cell Membranes and Transport</u> – Page 2

I. <u>Transport Across Membranes</u>

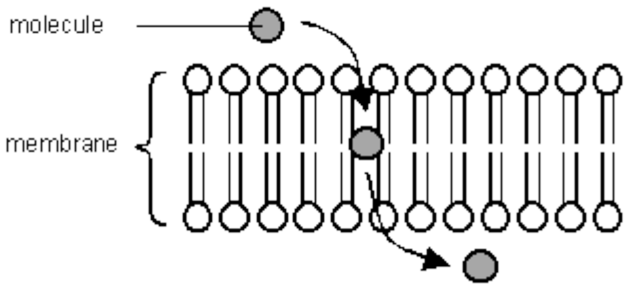
		Completed
1.	Look at the PowerPoint Cell Transport	
2.	Read about the transport of materials across membranes • Rowlands p38-42 • Toole p66-70 • Hand-out 1.3c Transport Across Membranes • Hand-out 1.3d The Cell Surface Membrane Factsheet • Hand-out 1.3e Active Transport • Hand-out 1.3f The Fluid Mosaic Model	
3.	Assessed Homework • Complete the essay on the transport of substances across membranes	

Movement across Cell Membranes

Cell membranes are a barrier to most substances, and this property allows materials to be concentrated inside cells, excluded from cells, or simply separated from the outside environment. This is compartmentalisation and it is essential for life, as it enables reactions to take place that would otherwise be impossible. Eukaryotic cells can also compartmentalise materials inside organelles, this enables the cell to create optimal conditions for different reactions occurring within the cell. Obviously, materials need to be able to enter and leave cells, and there are five main methods by which substances can move across a cell membrane:

1. Diffusion
2. Osmosis
3. Facilitated diffusion
4. Active Transport
5. Endo and Exocytosis

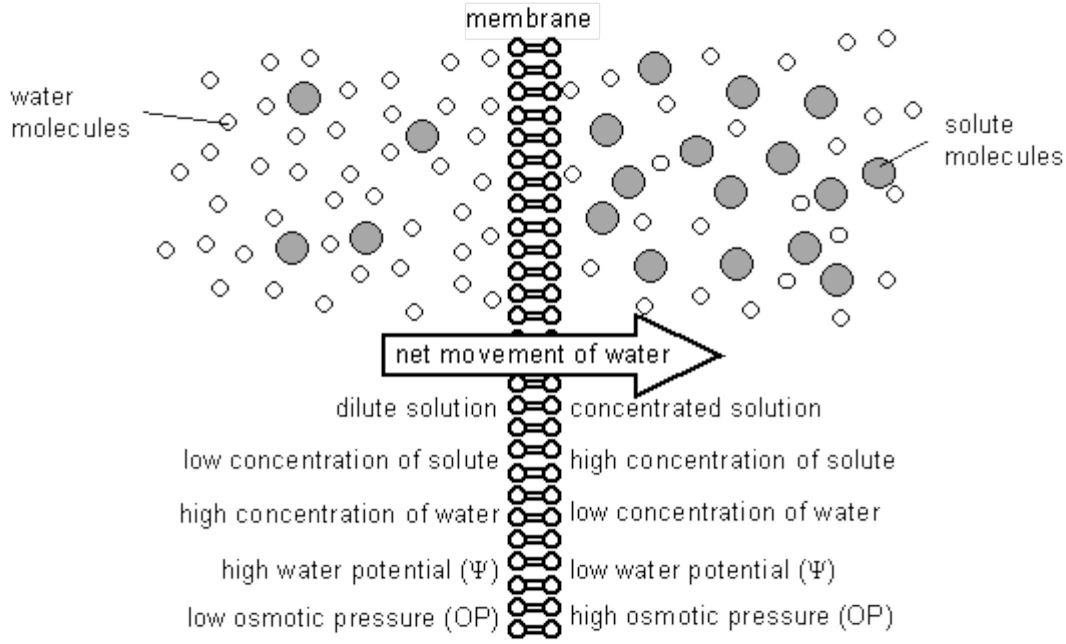
1. Diffusion



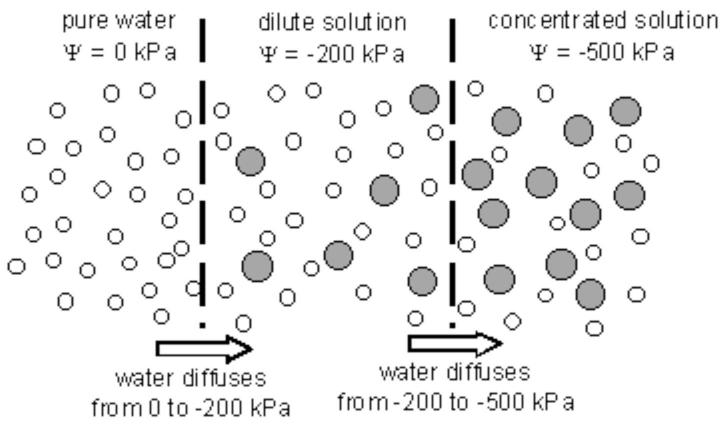
A few substances can diffuse directly through the lipid bilayer part of the membrane. The only substances that can do this are **lipid-soluble** / **non-polar** molecules such as steroids, or very small polar molecules such as and H_2O and uncharged molecules such as O_2. For these molecules the membrane is no barrier at all. Since diffusion is (obviously) a passive diffusion process, no energy is involved and substances can only move down their concentration gradient. Diffusion across the membrane phospholipid bilayer cannot be controlled by the cell, in the sense of being turned on then off.

2. Osmosis

Osmosis is a special type of diffusion that describes the movement of **water** across a membrane. It is in fact just normal diffusion across the lipid bilayer, but since water is so important and so abundant in cells (its concentration is about 50M), the diffusion of water has its own name - osmosis. The contents of cells are essentially solutions of numerous different solutes, and the more concentrated the solution, the more solute molecules there are in a given volume, so the fewer water molecules there are. Water molecules can diffuse freely across a membrane, but always down their concentration gradient, so water therefore diffuses from a dilute to a concentrated solution.



Water Potential. Osmosis can be quantified using water potential, so we can calculate which way water will move, and how fast. Water potential (Ψ, the Greek letter psi, pronounced "sy") is simply the effective concentration of water. It is measured in units of pressure (Pa, or usually kPa), and the rule is that water always "falls" from a high to a low water potential (in other words it's a bit like gravity potential or electrical potential). 100% pure water has $\Psi = 0$, which is the highest possible water potential, so all solutions have $\Psi < 0$, and you cannot get $\Psi > 0$.

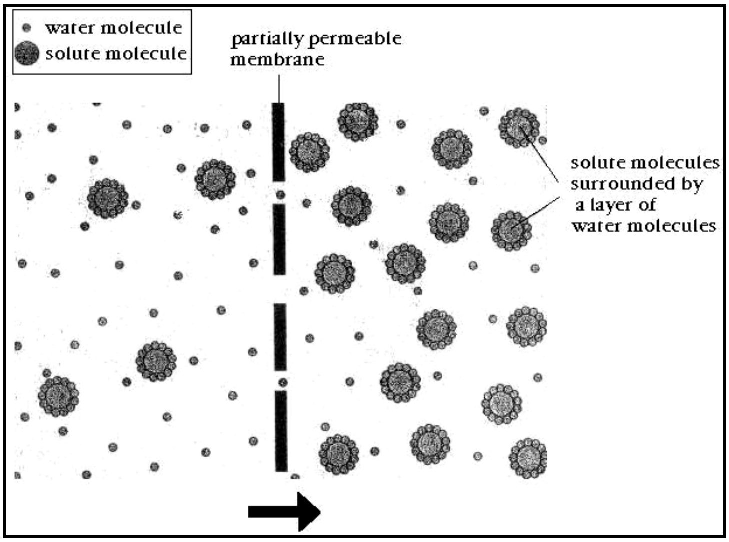


Water potential is a measure of the pressure that water molecules exert on a membrane. The higher the concentration of water molecules the higher the pressure they exert and the higher the water potential. Pure water has the greatest concentration of water molecules and therefore will exert the highest water potential. The value of the water potential of pure water is zero. As all other solutions have water potential less than this, they have negative values. For example a sucrose solution will have lower or more negative water potential than distilled water. The more concentrated a solution; the lower (or more negative) is its water potential. If you get confused with this think about temperature, a temperature of -15^0C is lower or more negative than a temperature of 0^0C.

Definition of Water Potential:

'The tendency for water to exit or enter a system or a cell it will enter by osmosis'.

Explaining Water Potential
Pure water has the highest water potential, because there is a high concentration of water molecules that are completely free to move about. When a solute such as sugar is dissolved in water there are proportionally fewer water molecules to move about and the water potential is lowered.

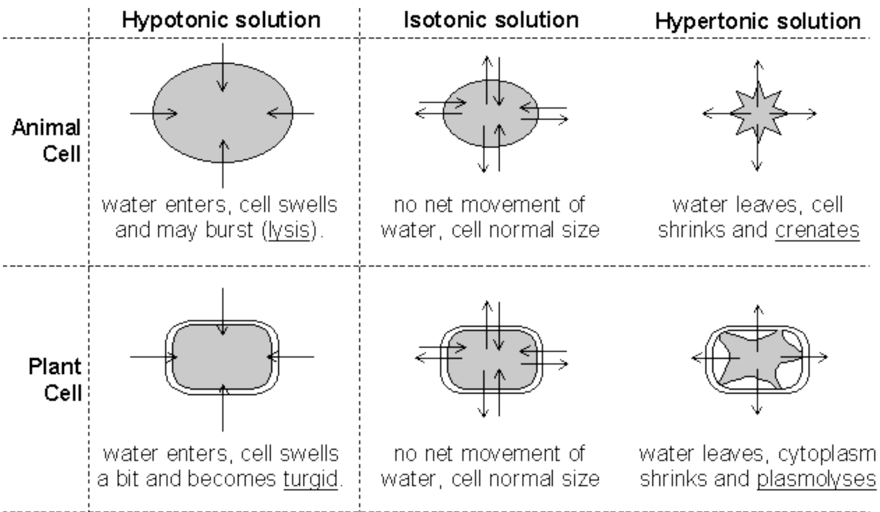


Look at the diagram above on the left hand side and right hand side of the membrane there are probably the same number of water molecules. However, on the left hand side where there are fewer solute molecules there are more water molecules free to move, therefore the water potential on the left hand side is higher than that on the right hand side.

Cells and Osmosis.
The concentration of the solution that surrounds a cell will affect the state of the cell, due to osmosis. There are three possible concentrations of solution to consider:

- Isotonic solution a solution of water potential (or concentration) equal to that of a cell
- Hypertonic solution a solution of lower water potential (or concentration) than a cell
- Hypotonic solution a solution of higher water potential (or concentration) than a cell

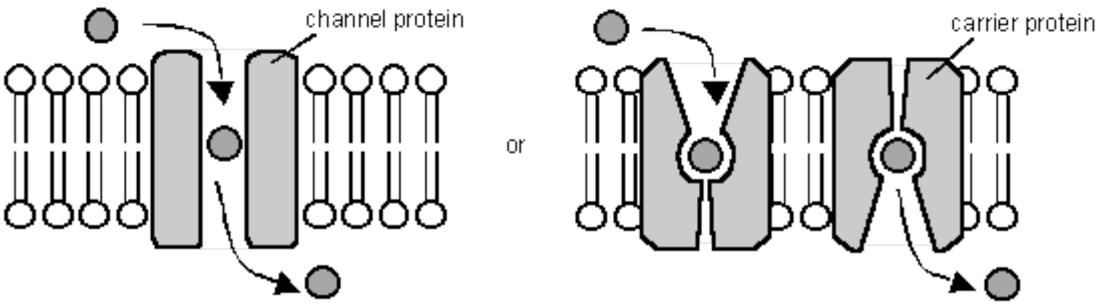
The effects of these solutions on cells are shown in this diagram:



These are problems that living cells face all the time. For example:

- Simple animal cells (protozoans) in fresh water habitats are surrounded by a hypotonic solution and constantly need to expel water using contractile vacuoles to prevent swelling and lysis.
- Cells in marine environments are surrounded by a hypertonic solution, and must actively pump ions into their cells to reduce their water potential and so reduce water loss by osmosis.
- Young non-woody plants rely on cell turgor for their support, and without enough water they wilt. Plants take up water through their root hair cells by osmosis, and must actively pump ions into their cells to keep them hypertonic compared to the soil. This is particularly difficult for plants rooted in salt water.

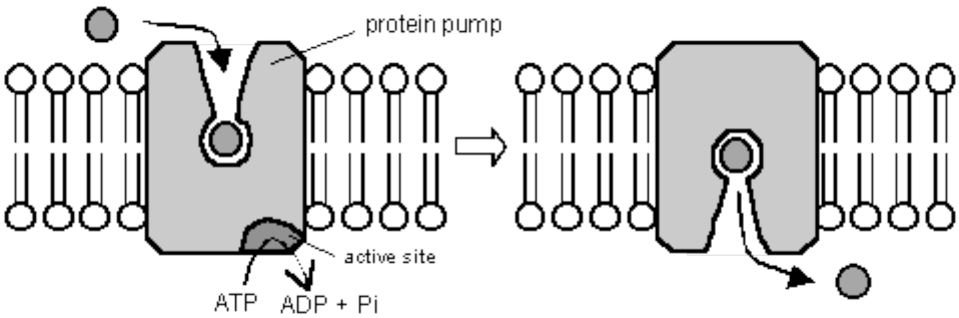
3. Facilitated Diffusion.



Facilitated diffusion is the transport of substances across a membrane by a trans-membrane protein molecule. The transport proteins tend to be specific for one molecule (a bit like enzymes), so substances can only cross a membrane if it contains the appropriate protein. As the name suggests, this is a passive diffusion process, so no energy is involved and substances can only move down their concentration gradient. There are two kinds of transport protein:

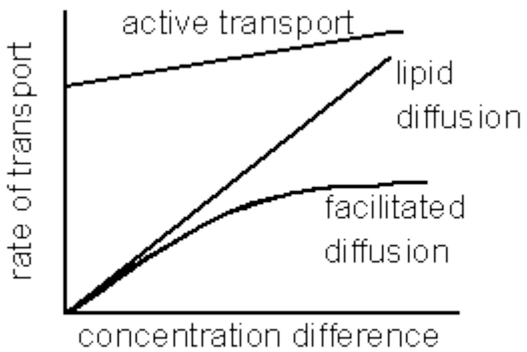
- Channel Proteins form a water-filled pore or channel in the membrane. This allows charged substances (usually ions) to diffuse across membranes. Most channels can be gated (opened or closed), allowing the cell to control the entry and exit of ions.
- Carrier Proteins have a binding site for a specific solute and constantly flip between two states so that the site is alternately open to opposite sides of the membrane. The substance will bind on the side where it at a high concentration and be released where it is at a low concentration.

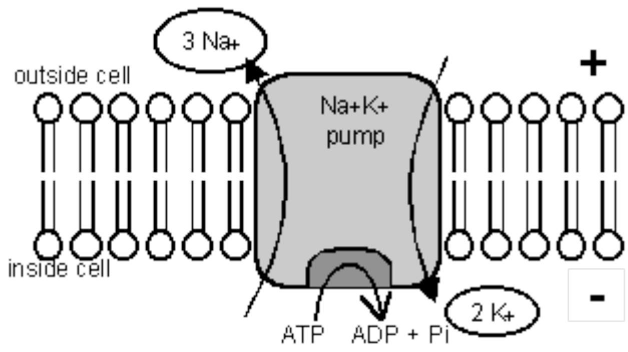
4. Active Transport (or Pumping).



Active transport is the pumping of substances across a membrane by a trans-membrane carrier protein (a protein pump) molecule. The protein binds a molecule of the substance to be transported on one side of the membrane, changes shape, and releases it on the other side. The proteins are highly specific, so there is a different protein carrier for each molecule to be transported. The protein carriers are also ATPase enzymes, since they catalyse the splitting of ATP to ADP + phosphate (Pi), and use the energy released to change shape and pump the molecule across the membrane. Pumping is therefore an active process, and is the only transport mechanism that can transport substances up or against the concentration gradient.

The Na^{+}/K^{+} Pump. This transport protein is present in the cell membranes of all animal cells and is the most abundant and important of all membrane pumps.





The Na^{+}/K^{+} pump is a complex pump, simultaneously pumping three sodium ions out of the cell and two potassium ions into the cell for each molecule of ATP split. This means that, apart from moving ions around, it also generates a potential difference across the cell membrane. This is called the membrane potential, and all animal cells have it. It varies from 20 to 200 mV, but it is always negative inside the cell when a cell is at rest. In most cells the Na^{+}/K^{+} pump runs continuously and uses 30% of all the cell's energy (70% in nerve cells).

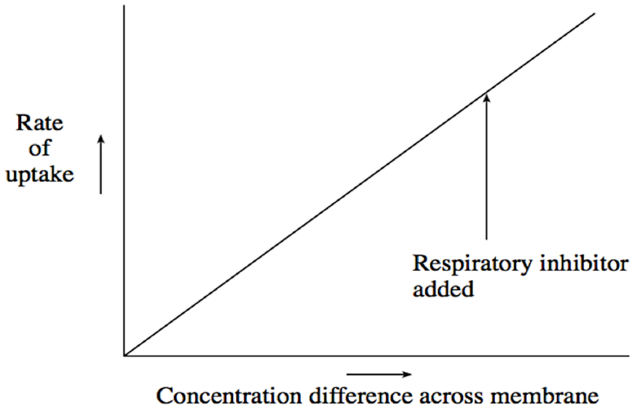
Rates of Transport Across the Membrane

The rate of diffusion of a substance across a membrane increases as its concentration gradient increases, but whereas lipid diffusion shows a linear relationship; facilitated diffusion has a curved relationship with a maximum rate. This is due to the rate being limited by the number of transport proteins. The rate of active transport also increases with concentration gradient, but most importantly it has a high rate even when there is no concentration difference across the membrane. Active transport stops if cellular respiration stops, since there is no energy.

The following graphs show the effect of an increasing concentration gradient on the rate of uptake of substances across a cell membrane. The effect of adding a respiratory inhibitor on the rate of uptake is also shown.

For **each** graph name the type of uptake involved and give reasons for your choice.

(i) Process A



Type of uptake .... [3]

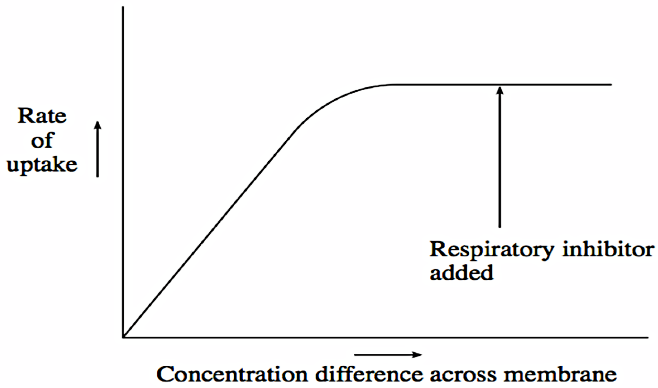
Reasons for choice ....

....

....

....

(ii) Process B



Type of uptake .... [3]

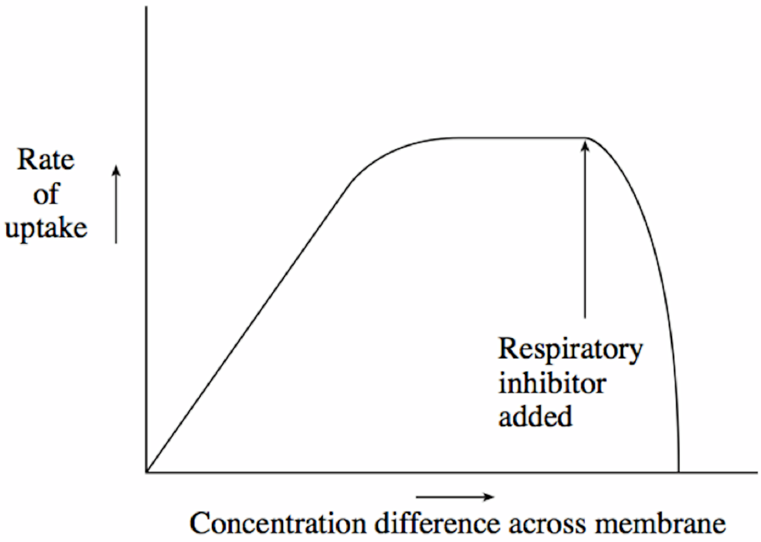
Reasons for choice ....

....

....

....

(iii) Process C



Type of uptake .... [3]

Reasons for choice ....

....

....

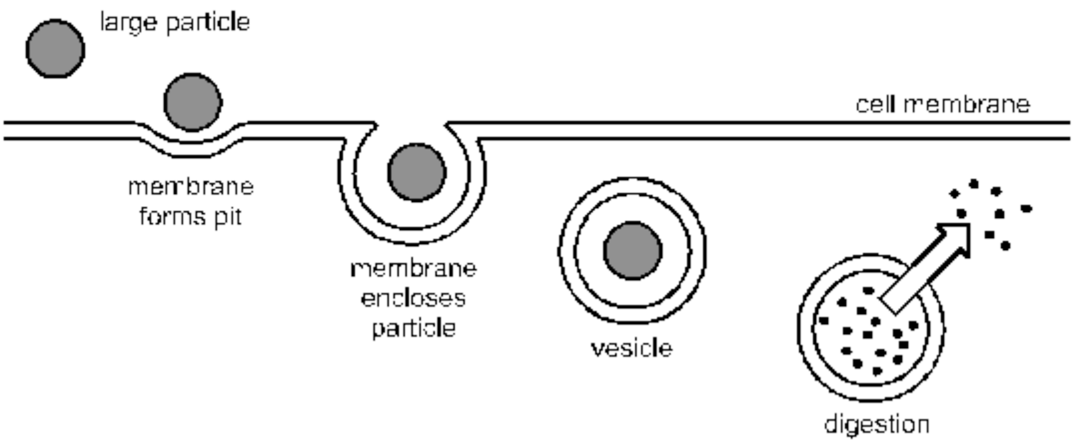
....

(Total 9 marks)

5.Endo and Exocytosis

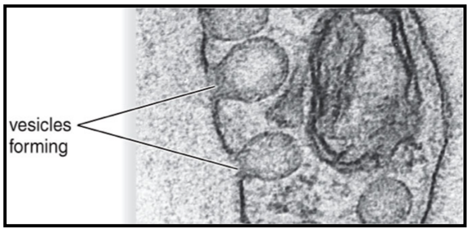
The processes described so far only apply to small molecules. Large molecules (such as proteins, polysaccharides and nucleotides) and even whole cells are moved in and out of cells by using membrane vesicles.

- **Endocytosis** is the transport of materials into a cell. A fold of the cell membrane encloses materials; this then pinches shut to form a closed vesicle. Strictly speaking the material has not yet crossed the membrane, it is usually digested and the small product molecules are absorbed by the methods above (facilitated and simple diffusion). When the materials and the vesicles are small (such as a protein molecule) the process is known as pinocytosis (cell drinking), and if the materials are large (such as a white blood cell ingesting a bacterial cell) the process is known as phagocytosis (cell eating).



- **Exocytosis** is the transport of materials out of a cell. It is the exact reverse of endocytosis. Materials to be exported must first be enclosed in a membrane vesicle, usually from the RER and Golgi body. Hormones and digestive enzymes are secreted by exocytosis from the secretory cells of the intestine and endocrine glands.

Sometimes materials can pass straight through cells without ever making contact with the cytoplasm by being taken in by endocytosis at one end of a cell and passing out by exocytosis at the other end.



Summary of Membrane Transport - Please complete

Method	Uses energy	Uses proteins	Specific	Controllable
Lipid Diffusion				
Osmosis				
Passive Transport				
Active Transport				
Vesicles				

Questions

1. How does active transport
   a. Resemble
   b. Differ from facilitated diffusion?

2. The data in the table below show the relative uptake of glucose and xylose (a 5 carbon sugar) from living intestine and from intestine that had been poisoned with cyanide. Cyanide greatly reduces the availability of ATP. Discuss these data.

	Relative rate of uptake by intestine	
Sugar type	**Without cyanide**	**With cyanide**
Glucose	100	28
Xylose	18	18

3. What factors will affect the rate of active transport?

4.

What do diffusion and osmosis have in common?

A. They only happen in living cells.

B. They require transport proteins in the membrane.

C. They are passive transport mechanisms.

D. Net movement of substances is against the concentration gradient.

5. What does facilitated diffusion across a cell membrane require?

	A pore protein	**ATP**	**A concentration gradient**
A.	yes	no	no
B.	no	no	yes
C.	yes	no	yes
D.	no	yes	no

6. What is the difference between simple diffusion and facilitated diffusion?

	Simple diffusion	**Facilitated diffusion**
A.	Rate decreases with increasing concentration gradient	Rate increases with increasing concentration gradient
B.	Faster movement of molecules	Slower movement of molecules
C.	Always involves a membrane	Never involves a membrane
D.	Uses any part of a membrane	Uses channels in the membrane

7. Which process allows the movement of molecules that are too large to enter through a cell surface membrane?

A active transport

B endocytosis

C exocytosis

D facilitated diffusion

8. Which of the following is a feature of exocytosis but **not** endocytosis?

A. Shape changes of a membrane

B. Vesicle formation

C. Use of ATP

D. Secretion

9. Cells in the adrenal gland produce the hormone epinephrine and store it in vesicles. To release epinephrine these vesicles are carried to the plasma membrane and fuse with it. What process is occurring?

A. Expulsion

B. Exchange

C. Excretion

D. Exocytosis

Bio Factsheet

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Transport Mechanisms in Cells

The internal environment of the cell is isolated from its surroundings by the cell membrane. The cell membrane regulates transport of substances in and out of cells (Factsheet 8 - The cell surface membrane).

This Factsheet will describe transport mechanisms which occur inside cells and their functions within the cells. (Similar mechanisms also operate in the cell surface membrane). The mechanisms are:

- **diffusion and facilitated diffusion.**
- **active transport.**
- **proton pumps.**
- **cytoplasmic streaming.**
- **transport in vesicles.**

The internal volume of the cell is huge compared with the size of the molecules within the cell. Some of these molecules need to be distributed fairly evenly throughout the cytoplasm, for example, amino acids (so that they stand a better chance of meeting and combining with transfer-RNA molecules for use in polypeptide synthesis). Other molecules need to be transported to and from specific locations in the cell. For example, polypeptides must be transported from the rough endoplasmic reticulum to the Golgi body (so that they can combine to make proteins, or combine with other substances to make, for example, nucleoproteins).

***Remember**:- water is often referred to as 'the universal solvent' because it will dissolve a very wide range of substances. It thus allows them to be transported, either by diffusion, in solution, through the body of water, or by actual flowing of the water itself, carrying the dissolved substances.*

Intracellular membranes

Membranes inside cells, forming such structures as mitochondria, chloroplasts, smooth and rough endoplasmic reticulum and Golgi body, all have a similar structure to the cell surface membrane, although the relative proportions of the molecular components may differ. For example, membranes surrounding chloroplasts contain very little carbohydrate. Intra-cellular membranes may:

- act as reaction surfaces,
- act as intracellular transport systems (vesicles),
- provide separate intracellular compartments, thus isolating different
- chemical reactions.

Intracellular transport thus requires transport of solutes to, away from, and across membranes.

Diffusion

Diffusion is defined as, 'the net movement of molecules or ions from a region of their high concentration to a region of their low concentration'. It will occur in the cell wherever a concentration gradient exists and will continue until the diffusing substance is evenly distributed. Examples of diffusion inside cells are:

- oxygen absorbed through the cell membranes of animals and plants, or released from the photosynthesising chloroplasts of plants, will diffuse towards the mitochondria where oxygen is being used in aerobic respiration.
- carbon dioxide absorbed into photosynthesising plant cells will diffuse from the cell membrane towards and into the chloroplasts, to be used in photosynthesis. Respiratory carbon dioxide in non-photosynthetic plant cells and in animal cells will diffuse from where it is produced, by decarboxylation reactions in the mitochondria and cytoplasm, to the cell membrane where it is released from the cell. (Some of the carbon dioxide will diffuse in the form of hydrogen carbonate ions).
- glucose and other sugars, amino acids and ions absorbed through the cell membranes of animal and plant cells will diffuse throughout the cell to where they are used. Glucose, amino acids and other products of photosynthesising cells will diffuse from the chloroplasts to where they are used in the cell.

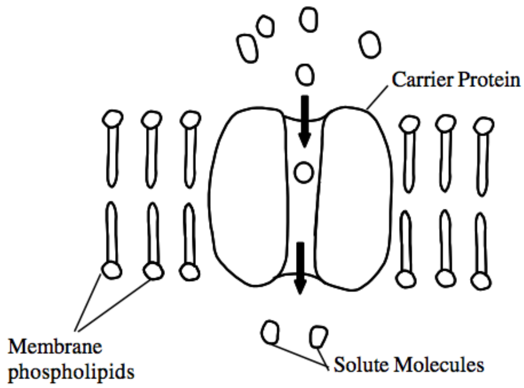
Facilitated diffusion is a process that enables diffusion to occur across membranes, for example, membranes of chloroplasts, mitochondria and endoplasmic reticulum. Facilitated diffusion is the 'passive movement of molecules down a concentration gradient across a membrane, and involves special carrier proteins in the membrane'. The carrier proteins may:

- contain special hydrophilic (water-liking) channels through which solutes can pass, or
- move in the membrane forming openings (gates), ferrying the solutes across.

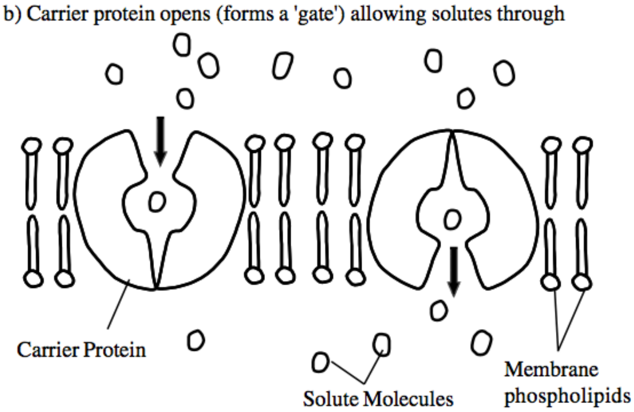
Facilitated diffusion does not require an energy source such as ATP to drive it.

Fig. 1. Facilitated diffusion

a) Hydrophilic channel allows solutes through



b) Carrier protein opens (forms a 'gate') allowing solutes through



In facilitated diffusion the carrier protein can transport the solute either way depending on the concentration gradient. Carrier proteins are specific to particular solute molecules. The carrier protein for the facilitated transport of glucose is called a **permease.** The glucose is bound to the permease on one side of the membrane and is released from the permease on the other side of the membrane, as in fig. 1.(b) above. In a plant cell, glucose may be released through chloroplast membranes and absorbed into plastids (amyloplasts) to be stored as starch.

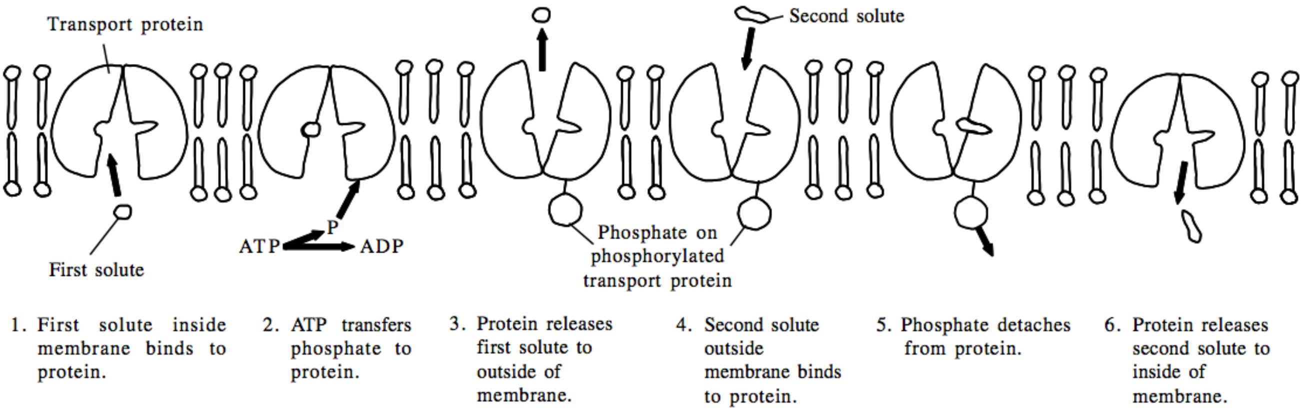
Active transport
Active transport is the movement of substances, usually against a concentration gradient, across a membrane, and involves the expenditure of energy. The energy usually comes from ATP, generated by respiration in the mitochondria. Active transport involves carrier proteins in the membrane. The carriers are specific to the substances they transport. The carriers may move:

- a single substance in a single direction (**uniport** carriers) For example, some calcium pumps.
- two substances in the same direction (**symport** carriers) For example, glucose-sodium pumps.
- two substances in opposite directions (**antiport** carriers). For example sodium-potassium pumps.

A calcium pump is involved with the regulation of calcium concentrations inside the cell. The cytoplasm normally has a calcium concentration of around 10^{-7} moles dm^{-3}. The spaces of the endoplasmic reticulum have a calcium concentration around 10^{-3} moles dm^{-3}. The calcium pump on the endoplasmic reticulum membranes pumps calcium from cytoplasm into the endoplasmic reticulum, creating a 10,000 fold concentration increase. A similar pump is used to pump calcium ions back into the sarcoplasmic reticulum of muscle, after contraction.

The exact mechanisms of active transport pumps are uncertain but a probable mechanism is illustrated in figure 2.

Fig. 2. Possible mechanism for active transport (antiport).



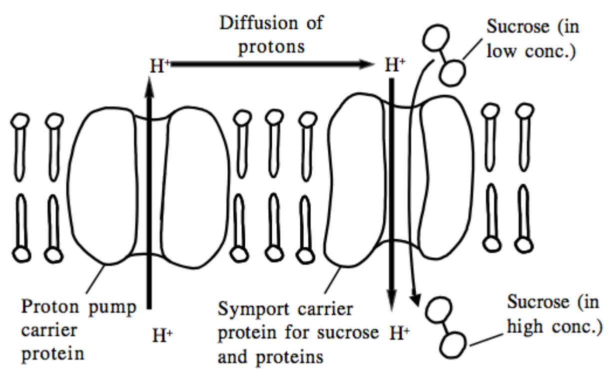
The ATP donates energy-rich phosphate to the transport protein thus activating it to bond with the specific solutes.

Proton pumps
These are active transport mechanisms use to transport hydrogen ions (protons) across membranes. Proton pumps are present in the vacuolar membranes (tonoplasts) of plant cells, yeasts and fungi, in the endoplasmic and lysosomal membranes of animal cells, in the inner mitochondrial membrane and in chloroplast thylakoid membranes.
In many cases proton pumps enable other molecules to be transported with the protons. For example:

- sucrose is transferred across membranes (for example, chloroplast membranes, cell surface membrane) in conjunction with protons,
- ATP in the mitochondria is released by a proton pump mechanism during aerobic respiration,
- ATP in the chloroplasts is released by a proton pump mechanism during the light-dependent stage of photosynthesis.

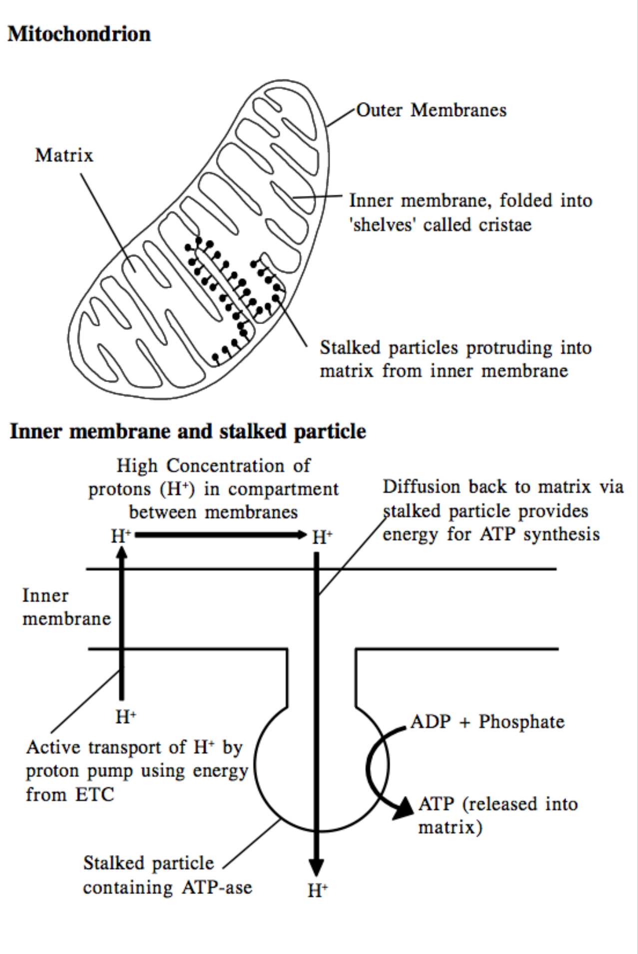
This is an example of **cotransport** in which the active transport of one substance indirectly drives the movement of another substance against a concentration gradient. The proton pump actively drives protons across the membrane (using energy from ATP). This forms a high concentration of protons which then diffuse back across the membrane via the symport carrier protein. This, by an unknown mechanism, enables sucrose to be actively transported across the membrane via the symport carrier, against the sucrose concentration gradient.

Fig. 3. Transport of sucrose across membranes



The proton pump operating across the inner mitochondrial membrane uses energy from the electron transport chain (ETC) to pump protons from the mitochondrial matrix into the compartment between the inner and outer mitochondrial membranes. The protons accumulate so that a steep concentration gradient exists between the compartment and the matrix. The inner membrane is impermeable to protons except through channels located in the stalked particles of the inner membrane. The protons diffuse back to the matrix through these channels and this provides energy to drive the synthesis of ATP from ADP and phosphate. The enzyme ATP-ase, in the stalked particles catalyses the ATP synthesis.

Fig. 4. ATP synthesis in the mitochondrion



The proton pump enabling ATP generation in chloroplasts works in a similar way. It is situated in the thylakoid membranes and releases the ATP to the stroma.

> ***Exam Hint**: – questions on cotransport have been asked several times in recent exams. The main example tested is the active transport mechanism of glucose (and galactose) which works in conjunction with a sodium pump (instead of a proton pump).*

Cytoplasmic streaming

Diffusion is a relatively slow process and so many cells speed up movement of materials by cytoplasmic streaming. Under the microscope, evidence of streaming can be seen in the movement of food vacuoles around an *Amoeba* cell, or in the movement of chloroplasts around the vacuole of a palisade mesophyll cell. Movement of such organelles, due to the streaming of cytoplasm, is called **cyclosis**. The streaming may involve all the cytoplasm or just part of it – plant cells tend to show streaming that circulates the cytoplasm in definite currents around the tonoplast membrane of the vacuole. Mass flow along the length of sieve tube elements, in phloem, is thought to involve cytoplasmic streaming.

The streaming is generated by active movements of actin microfilaments which are bound to the endoplasmic reticulum. Myosin, also bound to the endoplasmic reticulum, interacts with the actin filaments and pulls them moving the endoplasmic reticulum. This moves the nearby cytoplasm along. The interaction of actin and myosin requires energy from ATP.

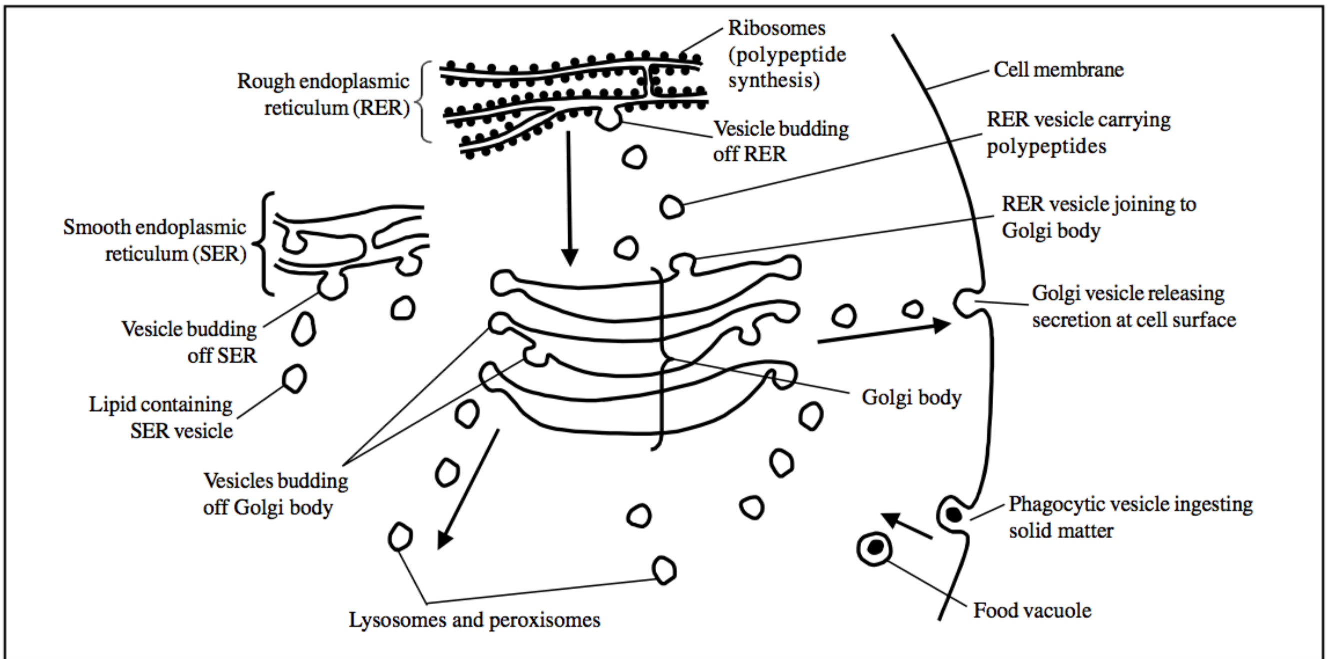
> ***Remember** – actin and myosin are contractile proteins They make up the structure of muscle fibres and are responsible for muscle contraction.*

Transport in vesicles

Vesicles are membrane bound sacs formed from various organelles within the cell used to transport substances throughout the cell or to specific locations of the cell. Examples are:

- vesicles budded off from the rough endoplasmic reticulum that migrate to the Golgi body and fuse with it. They carry polypeptides synthesized in the rough endoplasmic reticulum for processing into proteins and other derivatives by the Golgi body.

Fig 5. Examples of vesicles in a cell



- vesicles bud off from the Golgi body, containing substances synthesized by the Golgi body. These substances are often enzymes and the vesicles may:
  1. move to the cell surface membrane, fuse with it and release their contents to the outside (**secretory vesicles**).
  2. contain protein splitting enzymes (lysozyme) and disperse throughout the cytoplasm as **lysosomes**. These can be involved in intracellular digestion when required.
  3. contain peroxidase enzymes and disperse throughout the cytoplasm as **peroxisomes**.

  These are used to break down toxic hydrogen peroxide produced by cell metabolism.

- vesicles also bud off from the smooth endoplasmic reticulum. These transport lipid substances that may be dispersed throughout the cell, or released at the cell surface (for example, secretion of steroid hormones).

- vesicles budded off from the cell surface membrane into the cytoplasm. These may be **phagocytic vesicles** which engulf solid material from outside the cell and bring it into the cytoplasm (forming a food vacuole) or **pinocytic vesicles** which ingest liquid material from outside the cell to bring it into the cytoplasm.

Practice Questions

1. Read through the following passage about active transport and then complete it by inserting appropriate words or phrases into the gaps.

   Active transport can transport substances across membranes against a …………………….. . The substance is transported using a specific ……………… and requires the use of energy. The calcium pump in cells obtains energy from …….. . In mitochondria the synthesis of ATP, from the ………………., is enabled by a ………… pump. The driving energy for this comes from the ………………………… . A similar mechanism exists in the ……………. membranes of the chloroplast, enabling generation of ATP from the …………………… stage of photosynthesis. **Total 8**

2. Glucose can be transported across membanes by facilitated diffusion or by active transport in conjunction with sodium ions. Suggest possible mechanisms for:
   a) the transfer of glucose across a membrane by facilitated transport, and **4**
   b) the transfer of glucose across a membrane by active transport. (Hint – refer back to sucrose transport using a proton pump). **5**

   Total 9

3. Complete the following table relating to transport by cytoplasmic vesicles. **Total 4**

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides			
Protease enzymes			
Lipids			
Peroxidase enzymes			

Acknowledgements:
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4. Suggest explanations for the following:
   (a) Exposure of mitochondria to cyanide ions prevents ATP synthesis by the mitochondria. **4**
   (b) Cytoplasmic streaming in plant cells is slowed up by exposure to cold conditions. **4**
   (c) Liver (hepatic) cells contain more cytoplasmic vesicles than plant parenchyma cells. **4**

   Total 12

Answers

1. concentration gradient; carrier (protein); ATP; stalked particles; proton; electron transport chain/ETC; thylacoid; light-dependent; **Total 8**

2. (a) specific carrier protein in membrane reacts with glucose; carrier protein called a 'permease';
   releases glucose on the other side of the membrane/ forms a gate/ channel to allow passage of glucose;
   can go either way across the membrane depending on the concentration gradient; **4**
   (b) sodium pump carries sodium ions across membrane using a specific carrier protein; driven by energy from ATP;
   produces high concentration of sodium ions which can only diffuse back through the membrane at 'sodium – glucose gates';
   diffusion back of sodium ions provides energy to carry glucose molecules through membrane; ref to symport carrier; **5**

   Total 9 marks

3.

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides	Rough endoplasmic reticulum/RER	Rough endoplasmic reticulum/RER	Transport polypeptides to Golgi body;
Protease enzymes	Lysosomes	Golgi body	Intracellular digestion of proteins;
Lipids	Smooth endoplasmic reticulum/SER	Smooth endoplasmic reticulum/SER	Storage /secretion of lipids/steroids;
Peroxidase enzymes	Peroxisomes	Golgi body	Breakdown of toxic peroxides;

Total 4

4. (a) cyanide ions block cytochrome oxidase/prevent the electron transport chain from working;
   thus no energy is available to drive the proton pumps on the inner membrane;
   thus no protons/hydrogen ions diffuse back through the stalked particles to the matrix;
   thus ATP-ase in the stalked particles is not activated to synthesise ATP from ADP and phosphate; **4**

   (b) cytoplasmic streaming requires ATP as energy source;
   to make actin microfilaments combine with myosin, thus pulling the endoplasmic reticulum which moves the cytoplasm;
   ATP synthesis/use requires enzymes/ref ATP-ase;
   enzymes are temperature dependent and slow up in cold conditions; **4**

   (c) liver cells are metabolically much more active compared to plant parenchyma cells;
   synthesize many proteins/plasma proteins/fibrinogen and so many RER vesicles will be present;
   synthesize and store lipids so many SER vesicles will be present;
   detoxify peroxides and so many peroxisomes will be present; **4**

   Total 12

Bio Factsheet

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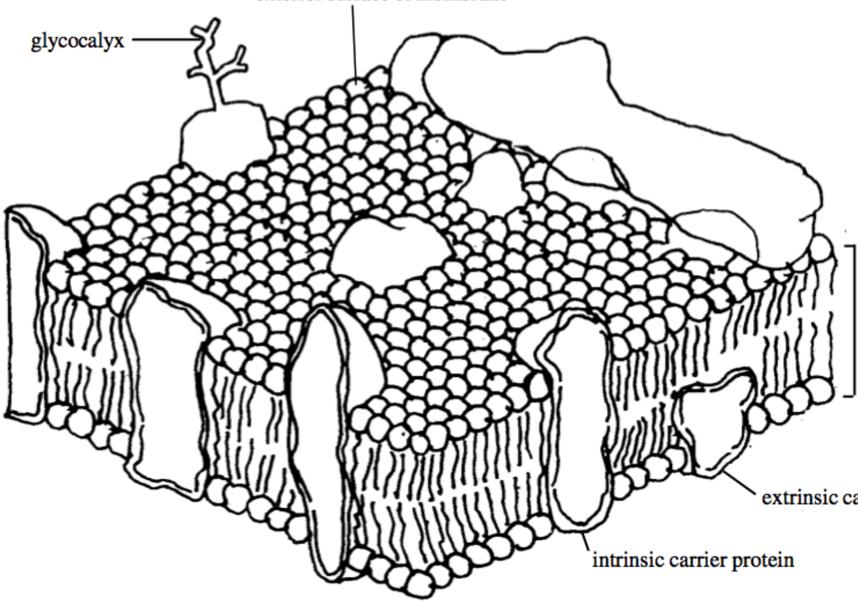
Active Transport

Active transport is the movement of molecules or ions across a differentially permeable membrane up a concentration or electrochemical gradient. Active transport is not passive, it requires ATP. In fact, in some cells nearly 50% of all the energy used is for active transport.

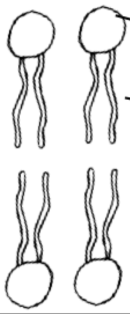
Active transport involves transport proteins. These proteins span the cell surface membrane (Fig 1).

Fig 1. Cell surface membrane (fluid mosaic model)



Glycocalyx -	allow cell recognition
Proteins -	intrinsic: span the membrane extrinsic: embedded in one half
Lipids -	phospholipids, glycolipids, cholesterol

The phospholipid bilayer



The hydrophobic tails spontaneously align themselves away from both the outside of the cell and the cytoplasm, since these are both aqueous

Transport proteins may move:
- A single substance in a single direction across a membrane
- Two substances in the same direction across a membrane
- Two substances in opposite directions across a membrane

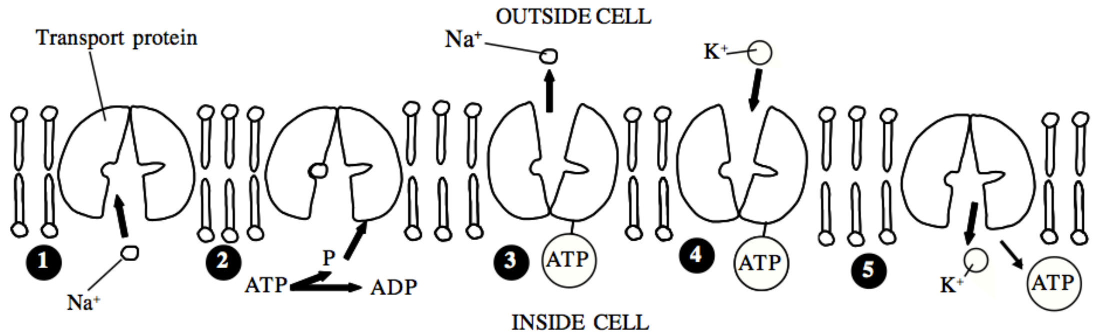
The process of active transport is still not fully understood. However, it is the general principles only that are important at this level and these can be illustrated by a form of active transport that occurs in almost every animal cell: the sodium-potassium pump (Fig 2).

Exam Hint: *You do not need to be able to reproduce Fig 1. However you may be asked to:*
1. *Draw a simple diagram of the phospholipid bilayer and recall its approximate width*
2. *Describe the functions of the phospolipids, proteins and the glycoycocalyx*
3. *Explain how the properties of the phospholipids influence the properties of the membrane*

The sodium - potassium pump

The sodium concentration is much greater outside the cell than inside it. There is therefore a tendency for sodium ions to diffuse into the cell down their concentration gradient. In order to work against this tendency the cell uses active transport to push out more of the sodium ions. By removing sodium ions in this way the cell reduces the volume of water that enters it by osmosis. Thus, one function of the sodium-potassium pump is to help the cell regulate its volume.

Fig. 2. Sodium-potassium pump

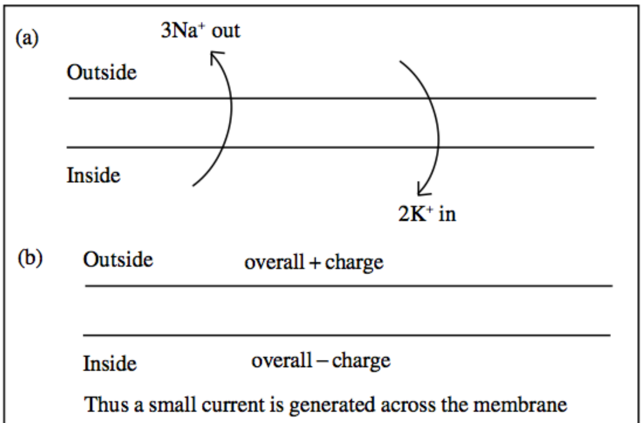


The ATP donates energy-rich phosphate to the transport protein thus activating it to bond with the specific solutes.

1. Sodium ions bind to the transport protein at specific binding site
2. This triggers hydrolysis of ATP into ADP and phosphate. The phosphate binds to the protein, phosphorylating it.
3. Phosphorylation causes the protein to change shape. This propels the sodium ion to the other side of the membrane i.e out of the cell, allowing it to enter the tissue fluid that bathes the cell.
4. Potassium ions in the tissue fluid now bind to the protein at their specific binding site (which is a different site to where the sodium ions bond).
5. This triggers dephosphorylation of the protein (i.e. the phosphate becomes detached from the protein carrier). Dephosphorylation causes the protein to change back to its original shape and this propels the potassium ion into the cell.

For each cycle of the pump, i.e. for each ATP molecule used, three sodium ions are expelled and two potassium ions are brought in. The net effect is to make the inside of the cell less positively charged i.e. more negatively charged relative to the outside (Fig 3). Thus, an electric current is generated across the membrane. In nerve cells, this is the basis of the membrane potential.

Fig 3 Sodium and potassium ions create the membrane potential



The major examples of active transport that feature on A level and Scottish Higher specifications are summarised in Table 1.

Table 1. Active Transport in animals and plants

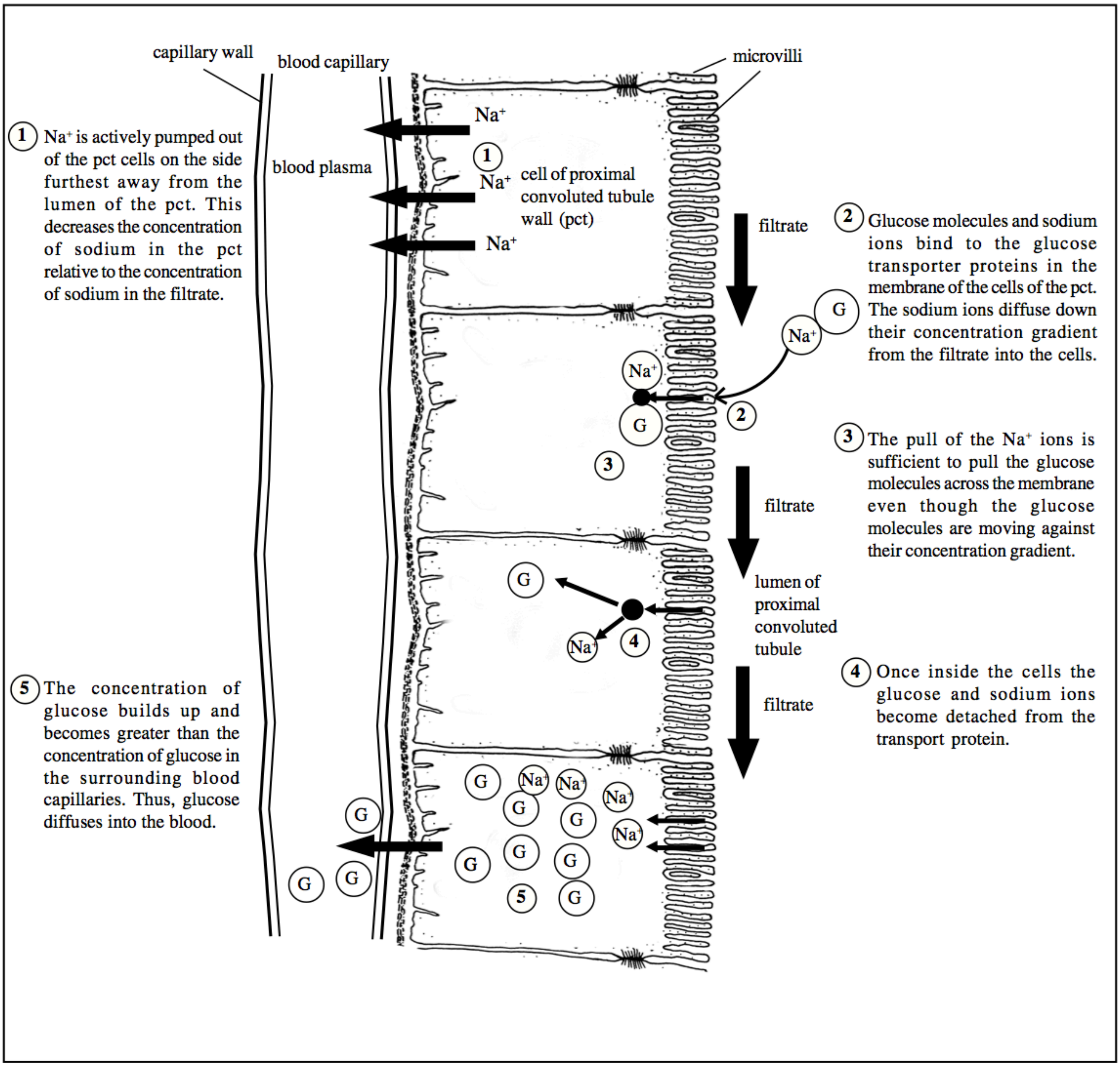
Location	**Process**
Root hair cells	Active transport of ions into the root hair
Guard cells of stomata (stomatal opening)	K^+ ions pumped into guard cells from epidermal cells. This lowers the water potential of the guard cells, drawing water in osmotically. Guard cells swell but the toughened wall around the pore is stiff and the pore of the stomata is pulled open
Placenta	Amino acids are actively transported from the mother to the foetus
Almost all animal cells	Sodium-potassium pump maintains low intracellular sodium concentration, helping to regulate cell volume and generating a resting potential
Proximal convoluted tubules of kidney	Active transport of sodium ions allows reabsorption of glucose from the filtrate

Examples of Active Transport

The proximal convoluted tubules of the nephron

Remember that the glomerular filtrate that enters the lumen of the cells of the convoluted tubule contains many substances that the body wishes to reabsorb: glucose and amino acids being good examples. Fig 4 shows how reabsorption of glucose is achieved.

Fig 4. Reabsorption in the proximal convoluted tubules



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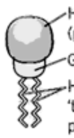
Interactive Information Revision **iPages**

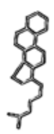
The fluid mosaic model for membranes: the key points

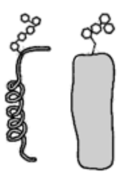
Membrane components and their functions

Phospholipid



Cholesterol


Regulates membrane fluidity



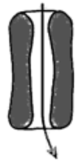
Glycoprotein

Cell signalling, cell recognition and binding cells together

Glycolipid

Carbohydrate, attached to lipid/phospholipid

Cell signalling and cell recognition



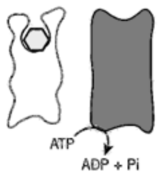
Channel protein

Protein with specific shape that complements the shape of a substance to be transported across the membrane

Used in facilitated diffusion

Cell signalling

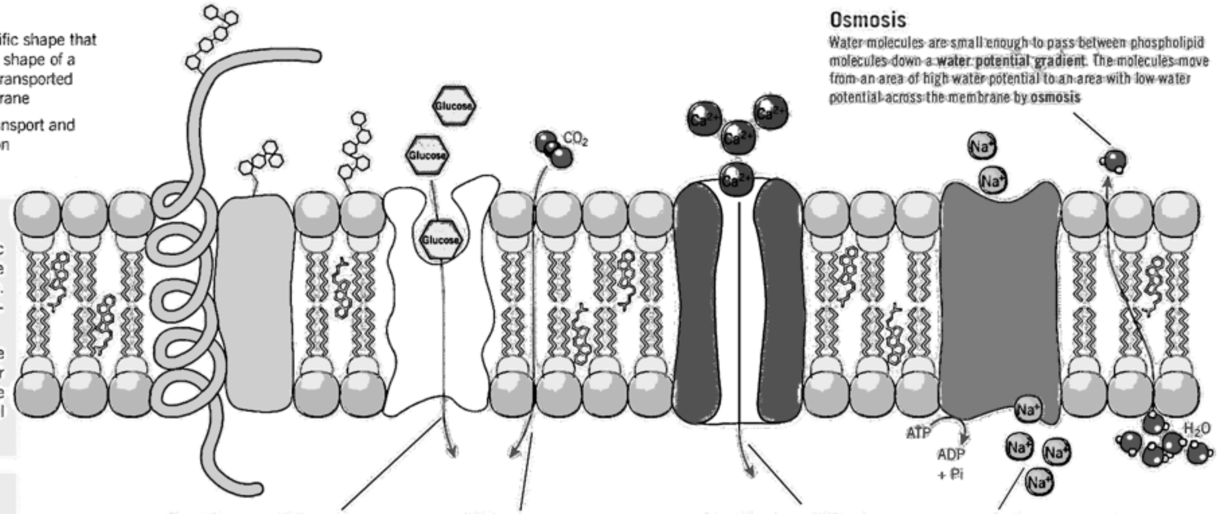
Receptors on cells bind to hormones, drugs and other cells, leading to a series of reactions within the cell



Carrier protein

Protein with specific shape that complements the shape of a substance to be transported across the membrane

Used in active transport and facilitated diffusion



Osmosis

Water molecules are small enough to pass between phospholipid molecules down a **water potential gradient**. The molecules move from an area of high water potential to an area with low water potential across the membrane by **osmosis**

Facilitated diffusion

Large, water-soluble substances cannot pass between the lipid molecules and so are carried through the membrane by **carrier proteins** down a concentration gradient by **facilitated diffusion**

Diffusion

Small, lipid-soluble substances can pass through the lipid bilayer — between the phospholipid molecules — down a concentration gradient by **diffusion**

Facilitated diffusion

Polar, water-soluble substances that cannot pass through the membrane between lipid molecules can be transported via specific **channel proteins** down a concentration gradient by facilitated diffusion

Active transport

Water-soluble substances that must be moved against a concentration gradient require a **carrier protein** and **ATP**. This process is **active transport**

Temperature and permeability

- A high temperature boosts the kinetic energy of the component molecules of the membrane and the transported substance. The membrane becomes more permeable.
- Very high temperatures will denature the protein molecules, changing their shape and making the membrane more permeable. Eventually, the membrane will be destroyed.

Specialised membranes

- Different cells' membranes have varying properties, functions and capabilities. These depend on the glycoproteins, glycolipids, carrier proteins and channel proteins that are present.
- Some membranes are folded to increase surface area for transport or absorption, e.g. microvilli.
- Membranes are fluid, so they can be folded by an organism's cytoskeleton to form **vesicles**. This **active process** — it requires ATP — is part of **endocytosis**.
- Vesicles can fuse with the membrane as part of **exocytosis**.

Test for lipids

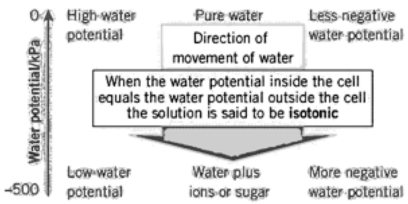
- Add the test substance to a test tube containing ethanol and mix.
- Add an equal volume of water to the test mix.
- If the test substance is a fat/lipid, the resulting mix is a cloudy, white emulsion.
- Reason: lipids are soluble in ethanol.

Factors affecting the rate of diffusion

- **Surface area**. Increasing the surface area increases the rate of diffusion.
- **Concentration gradient**. Increasing the concentration gradient increases the rate of diffusion.
- **Temperature**. Increasing the temperature increases the rate of diffusion.
- **Diffusion distance**. Increasing the diffusion distance **decreases** the rate of diffusion.

Water potential

Osmosis is the movement of water molecules down a water potential gradient across a partially permeable membrane. Water molecules will move from an area of high water potential (e.g. pure water) to an area of low water potential (e.g. saline or sugar solutions). Water molecules move from a position of less negative to more negative water potential.

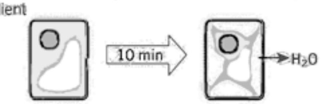


Plant cells placed in pure water will become **turgid**.

Water enters the cell by **osmosis** down a water potential gradient

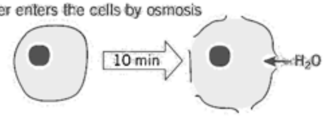
Plant cells placed in a saline solution will become flaccid or **plasmolysed**.

Water leaves cells by osmosis down a water potential gradient



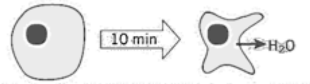
Animal cells placed in pure water will become **haemolysed**.

Water enters the cells by osmosis



Animal cells placed in a saline solution will become **crenated**.

Water leaves the cells by osmosis



biologicalreview*online*

- Web links for further reading
- Specification links
- Interactive quizzes
- 'Membranes' tutorial

www.philipallan.co.uk/biologicalreview see page 33 for full access details

These *iPages* and the accompanying online materials have been written by **Catherine Haworth**, Cardinal Newman College, Lancs

Task – In and out of cells

This task will involve reorganizing facts about the movement of substances into and out of a cell. You have to cut out the facts and then sort them out and rewrite them into a logical account. One of the aims of this task is to help you to practice writing an essay, concentrating on its structure and quality of English without having to worry too much about the content. The idea is not to find a correct sequence and copy out the sentences word for word, but to produce your own individual piece of writing. You may not understand all the statements below and will have to use textbooks and other reference material.

Information relevant to diffusion, osmosis, facilitated diffusion and active transport.
Active transport requires energy from cell metabolism.
All animal cells have sodium-potassium pumps in the plasma membrane
Gases and other small-uncharged molecules diffuse across the plasma membrane.
Ions diffuse down an electrochemical gradient as well as down a diffusion gradient.
Ions do not easily pass through the hydrophobic part of the membrane.
Molecules that are too large to diffuse through the phospholipid bilayer may diffuse through protein channels
Passive transport is movement of substances down a concentration gradient.
Small lipid soluble molecules such as steroid hormones diffuse through the phospholipid bilayer.
The change in the shape of the carrier protein causes the molecule to be taken through the protein to the other side of the membrane.
The charge across the membrane affects the diffusion of ions.
The phospholipid bilayer is not very permeable to monosaccharides.
There are different proteins for different molecules or ions.
These methods transport individual molecules or ions into out of cells.
The sodium-potassium pump uses energy from ATP to transport potassium into and sodium out of the cell.
To move a substance against a concentration gradient, a cell must use energy.
Carrier proteins change shape when the substance to be transported binds.
Carrier and channel proteins have a specific structure, which gives the molecule a distinctive shape.
Carrier proteins have a specific binding site.
Proteins may form hydrophilic channels through the membrane.
Carrier and channel proteins span the membrane.
Water diffuses from a high solute to a low solute gradient.
Water is small enough to pass between the phospholipid molecules
The movement of water across a partially permeable membrane is known as osmosis

The sentences below give information relevant to endo and exocytosis
A bacterium is engulfed in a pocket of plasma membrane which then breaks off and forms a vacuole with the bacterium inside.
A small pocket appears in the plasma membrane, which is then pinched off to form a vesicle inside the cell.
Endocytosis includes phagocytosis and pinocytosis
Large molecules such as proteins, are transported out of cells by exocytosis.
Macromolecules and larger particles, such as bacteria, are taken into the cell by endocytosis.
Pinocytosis is similar to phagocytosis, but pinocytosis takes in small droplets of the external solution, forming vesicles.
The vesicle membrane fuses with the plasma membrane.
This is a means of moving substances in bulk into or out of the cell.
Vesicles containing proteins for export break away from the Golgi apparatus.
Vesicles migrate to the plasma membrane.

Assessment

This essay will be marked out of 20.

A mark will be given for each coherent and logical point that is made up to a maximum of 20 marks.

All methods of transport need to be covered to gain full marks.